Evaluation of VSPAERO Analysis Capabilities for Conceptual Design of Aircraft with Propeller-Blown Wings

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Motivation

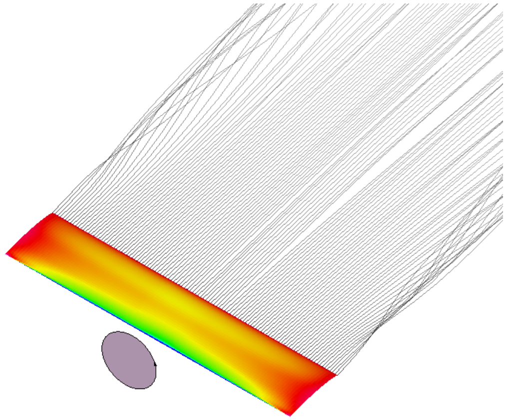
- Electric propulsion enables flexibility in propeller location on Advanced Air Mobility aircraft
- Increasing need for accurate, quick analysis of propeller-airframe interactions during conceptual design phase

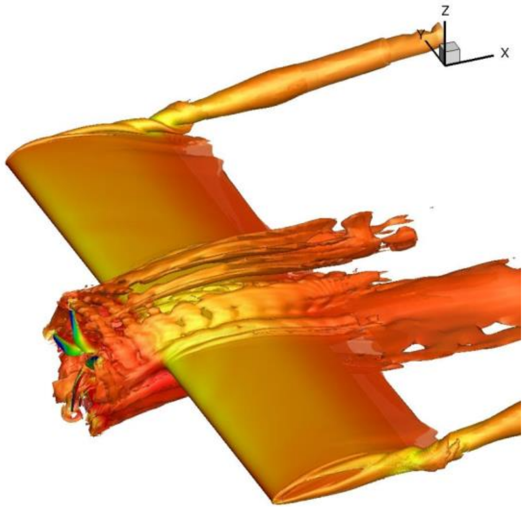
Tool Description: OVERFLOW and RoBIN

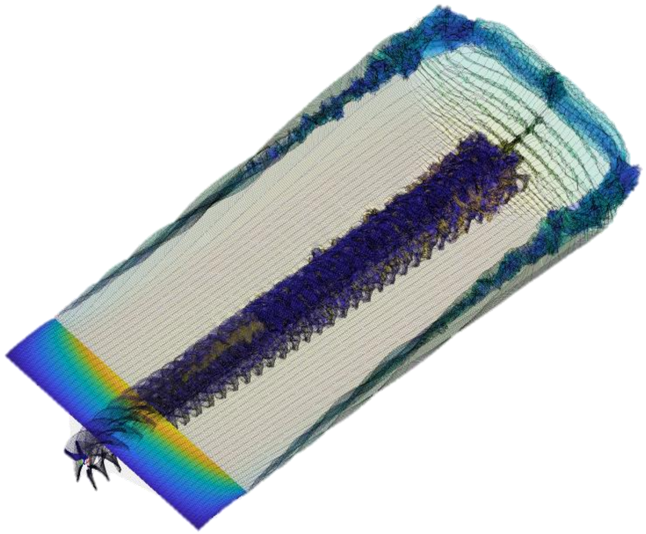
VSPAERO
- Vortex-Lattice Method (VLM)
- Inviscid

OVERFLOW[1]
- Reynolds-Averaged Navier-Stokes Computational Fluid Dynamics (CFD) solver

RoBIN[1]
- Vortex-Lattice Method
- Inviscid



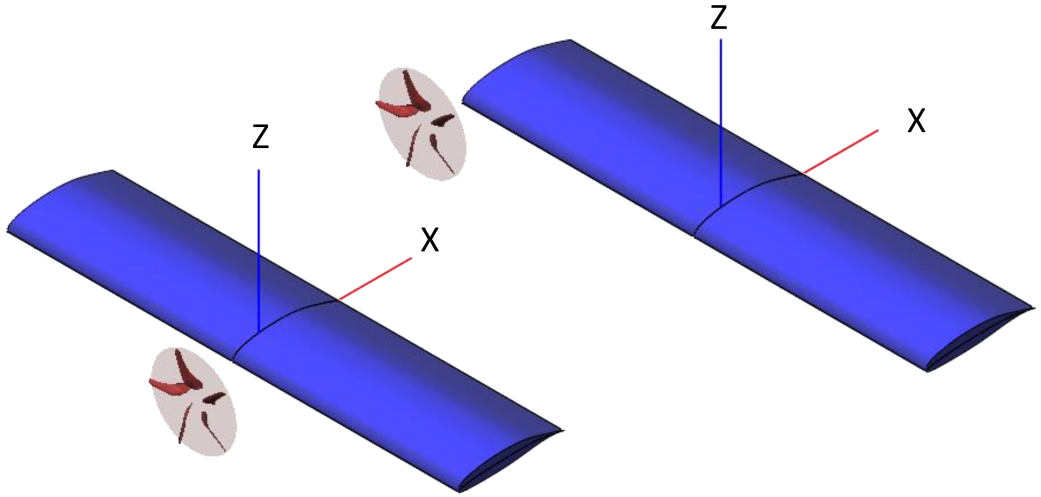




[1] Fei, X., "The Causes of Propeller Pitching Moment and the Conditions for Its Significance," Georgia Institute of Technology, 2021.

Setup: Geometry and Flow Conditions

- Constant chord, unswept wing, no dihedral
- X-57 wing root airfoil
- X-57 high-lift propeller
- Geometry is published in the OpenVSP Hangar [2]



Geometry	
Wing Chord (ft)	2.343
Wing Span (ft)	10
Propeller Diameter (ft)	1.890

Flow Conditions	
Angles of Attack (degrees)	-5, 0, 5, 10, 15, 20
Velocity (ft/s)	97.89
Reynolds Number	622,610
Tip Speed (ft/s)	450
Revolutions per minute	4550
Standard Sea Level Conditions	

[2] http://hangar.openvsp.org/vspfiles/526

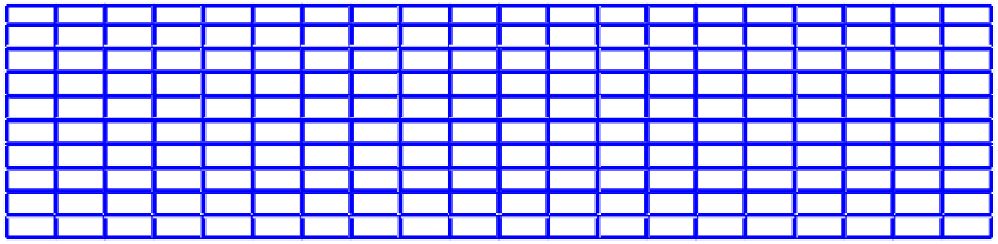
Mesh Convergence Studies

Goal

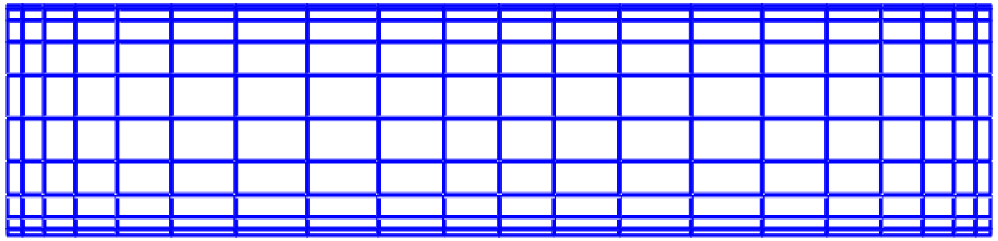
- Determine appropriate mesh settings to obtain sufficiently converged results in VSPAERO

Variables

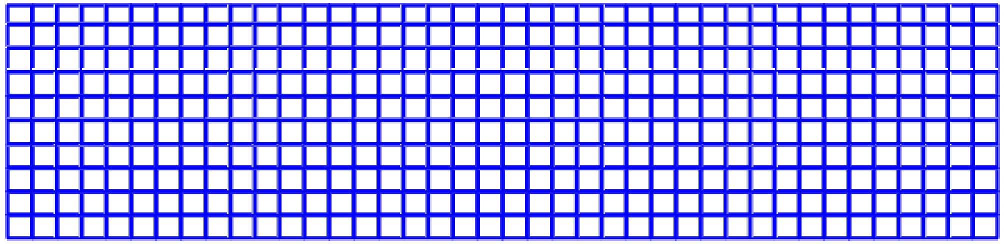
- Total Number of Panels
- Clustering settings at the root, tip, leading edge, and trailing edge
- Approximate panel aspect ratio
    - Note: ratio of number of spanwise to chordwise panels must be constant for each study



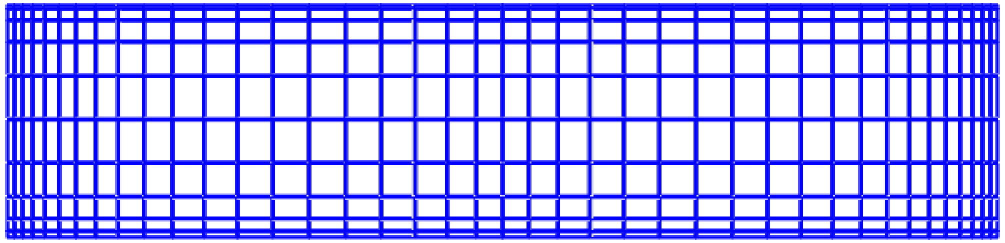
2:1 Aspect Ratio, No Clustering



2:1 Aspect Ratio, with Clustering



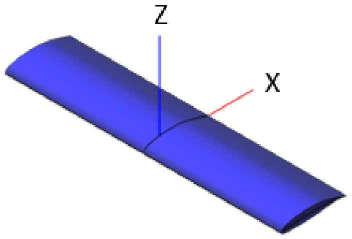
1:1 Aspect Ratio, No Clustering

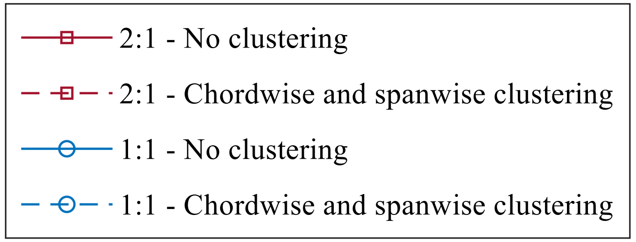


1:1 Aspect Ratio, with Clustering

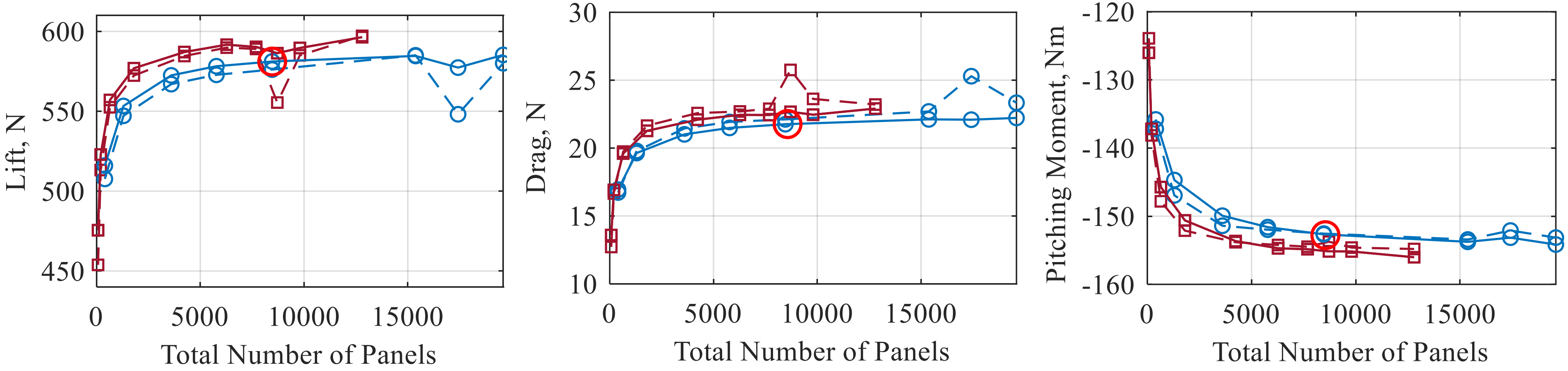
Above: Visualizations for 200 (2:1) and 400 (1:1) panels

Isolated Wing Mesh Study

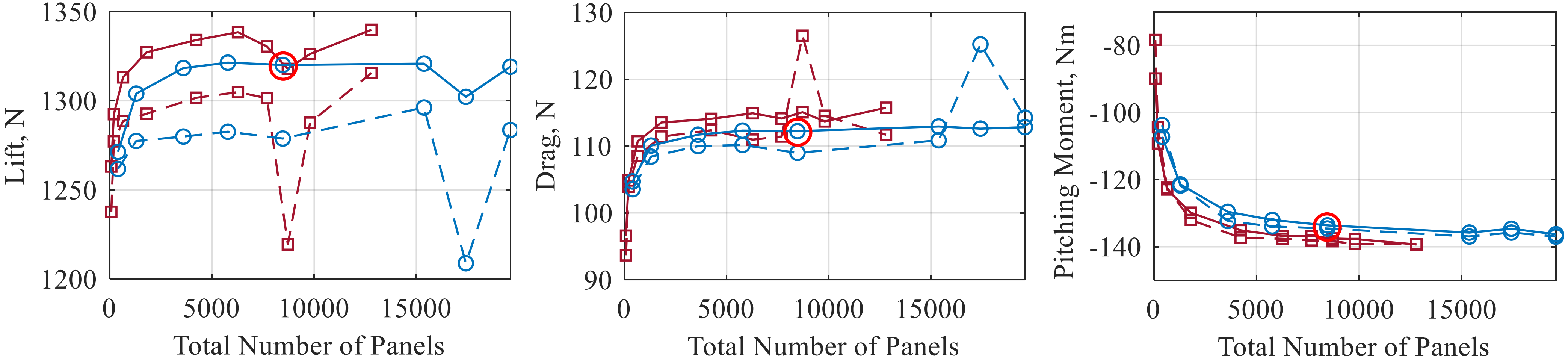




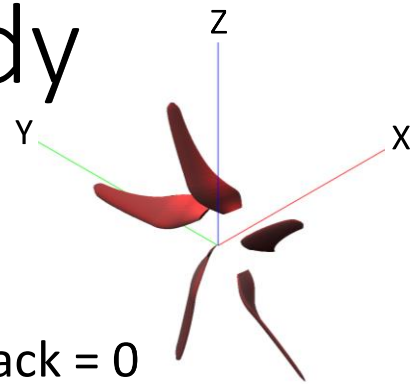
Angle of Attack = 0



Angle of Attack = 10

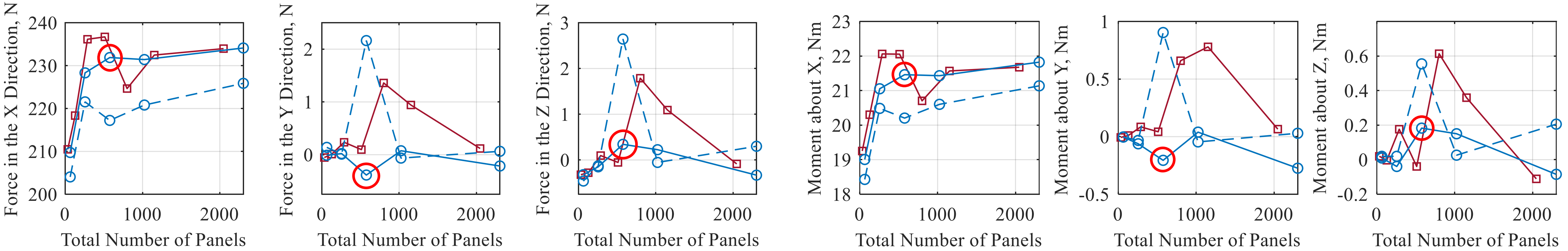


Isolated Propeller Mesh Study

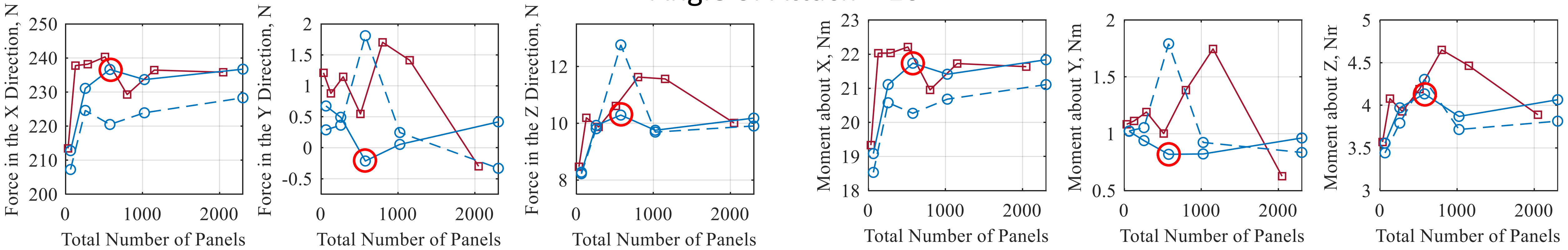


2:1 - No clustering
1:1 - No clustering
1:1 - Chordwise and spanwise clustering

Angle of Attack = 0



Angle of Attack = 10

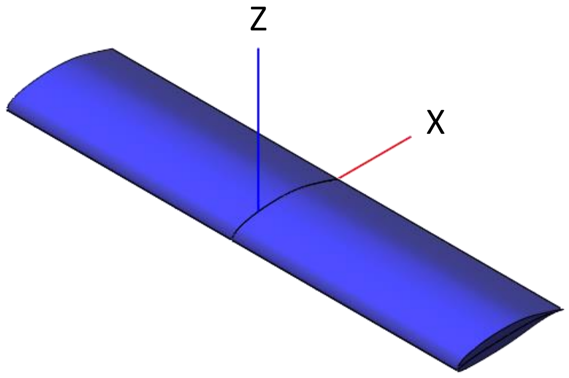


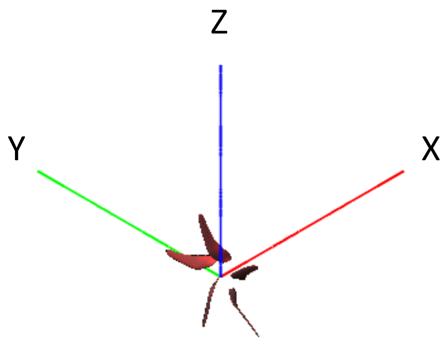
Mesh Study Lessons Learned

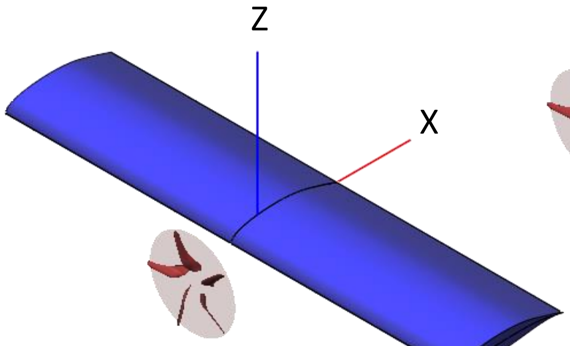
- A spike occurred for the isolated wing studies when chordwise number of panels was equal to 66
- 1:1 approximate panel aspect ratio with no clustering independently selected for both geometries
- Necessary to use a lot of panels to achieve convergence
- Applying different mesh settings caused curves to converge on different values

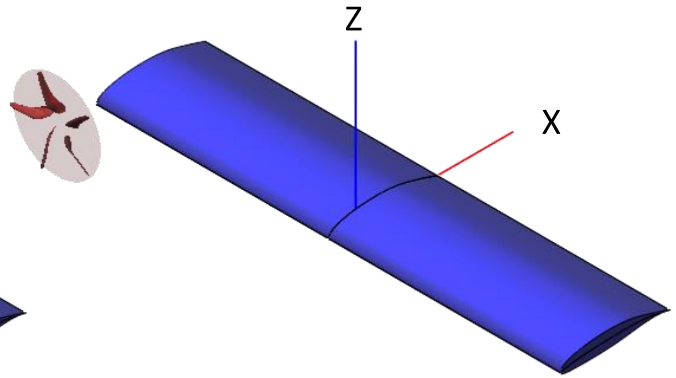
Propeller-Blown Wing Predictions

- VSPAERO force and moment predictions were obtained by implementing the geometry mesh settings recommended by the mesh convergence studies
- Analyses were run for the wing in isolation, propeller in isolation, and for the midspan and wingtip propeller-blown wing configurations



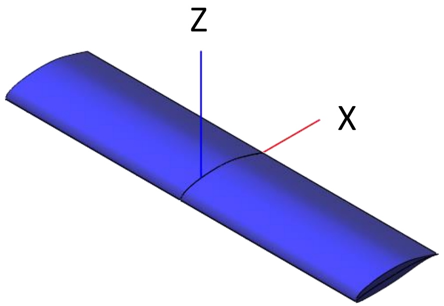




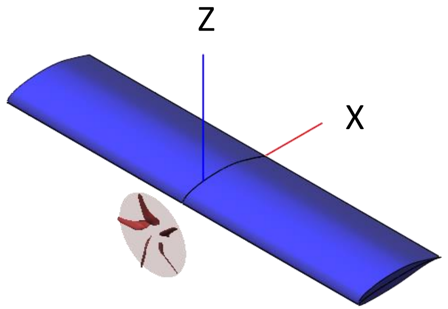


Wing Component: Forces

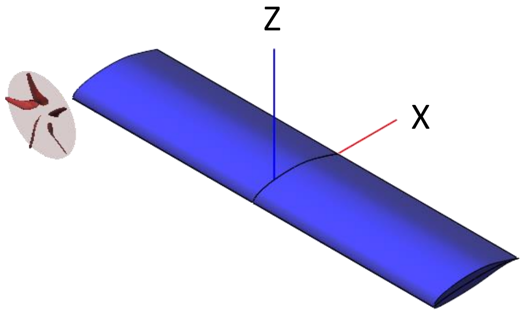
Wing in Isolation

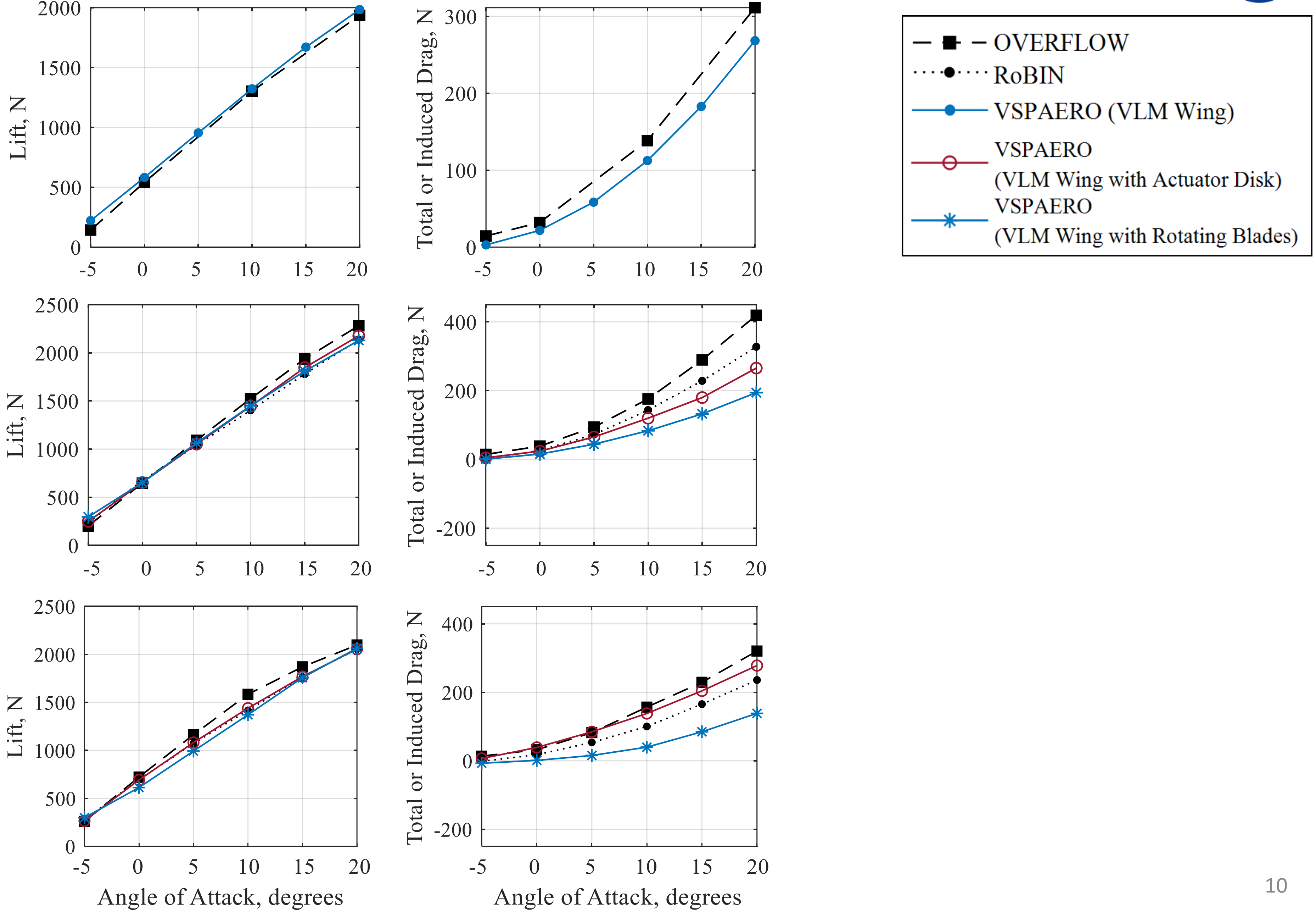


Midspan Configuration (Wing Component Only)



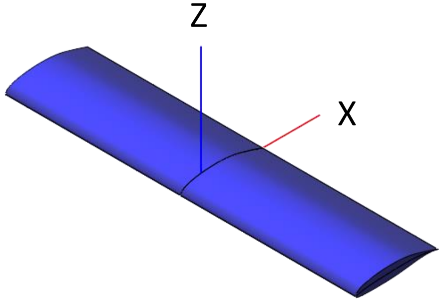
Wingtip Configuration (Wing Component Only)



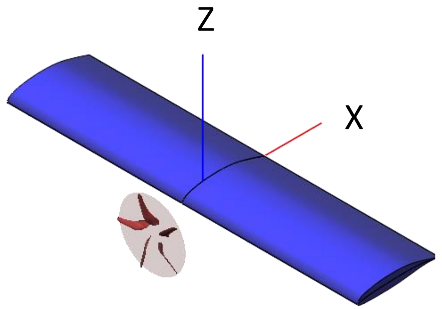


Wing Component: Moments

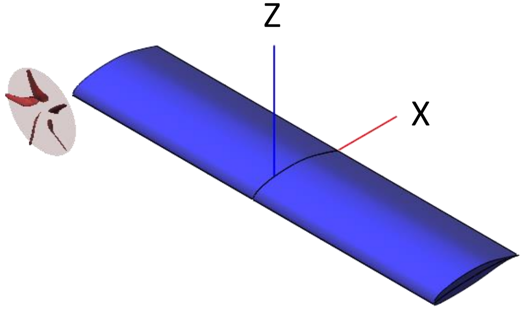
Wing in Isolation

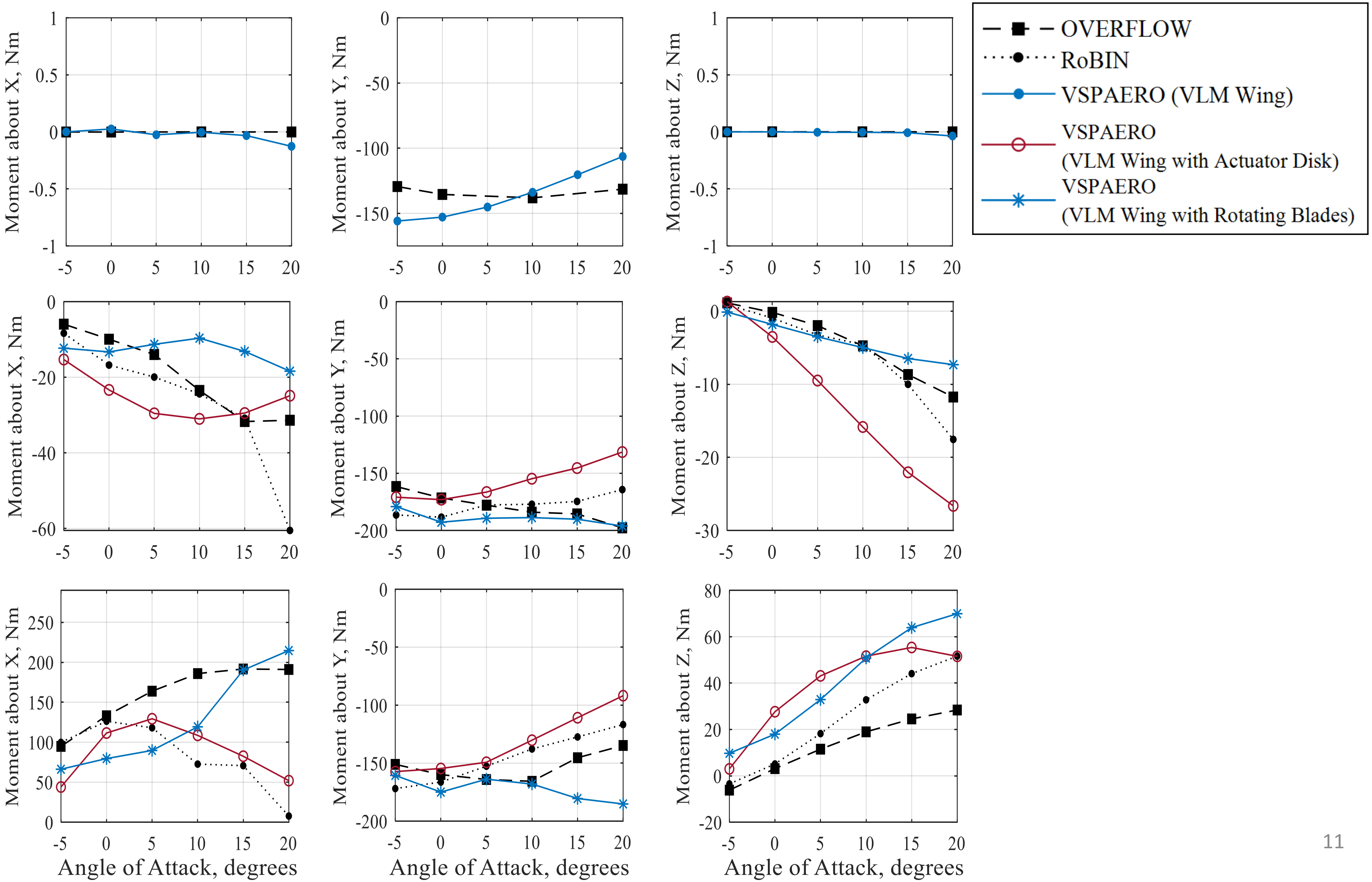


Midspan Configuration (Wing Component Only)



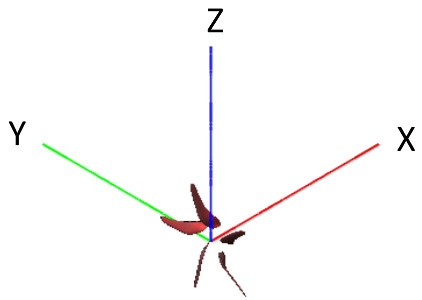
Wingtip Configuration (Wing Component Only)



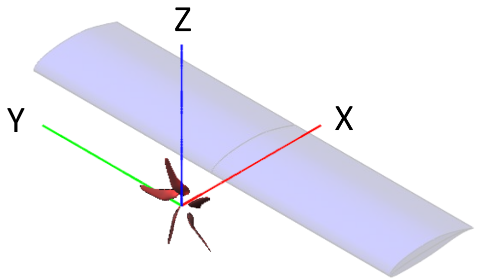


Propeller Component: Forces

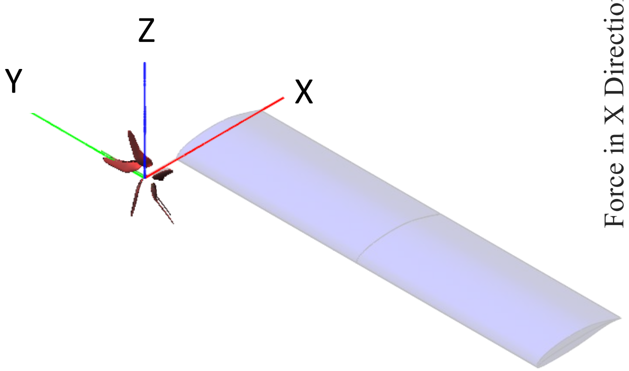
Propeller in Isolation

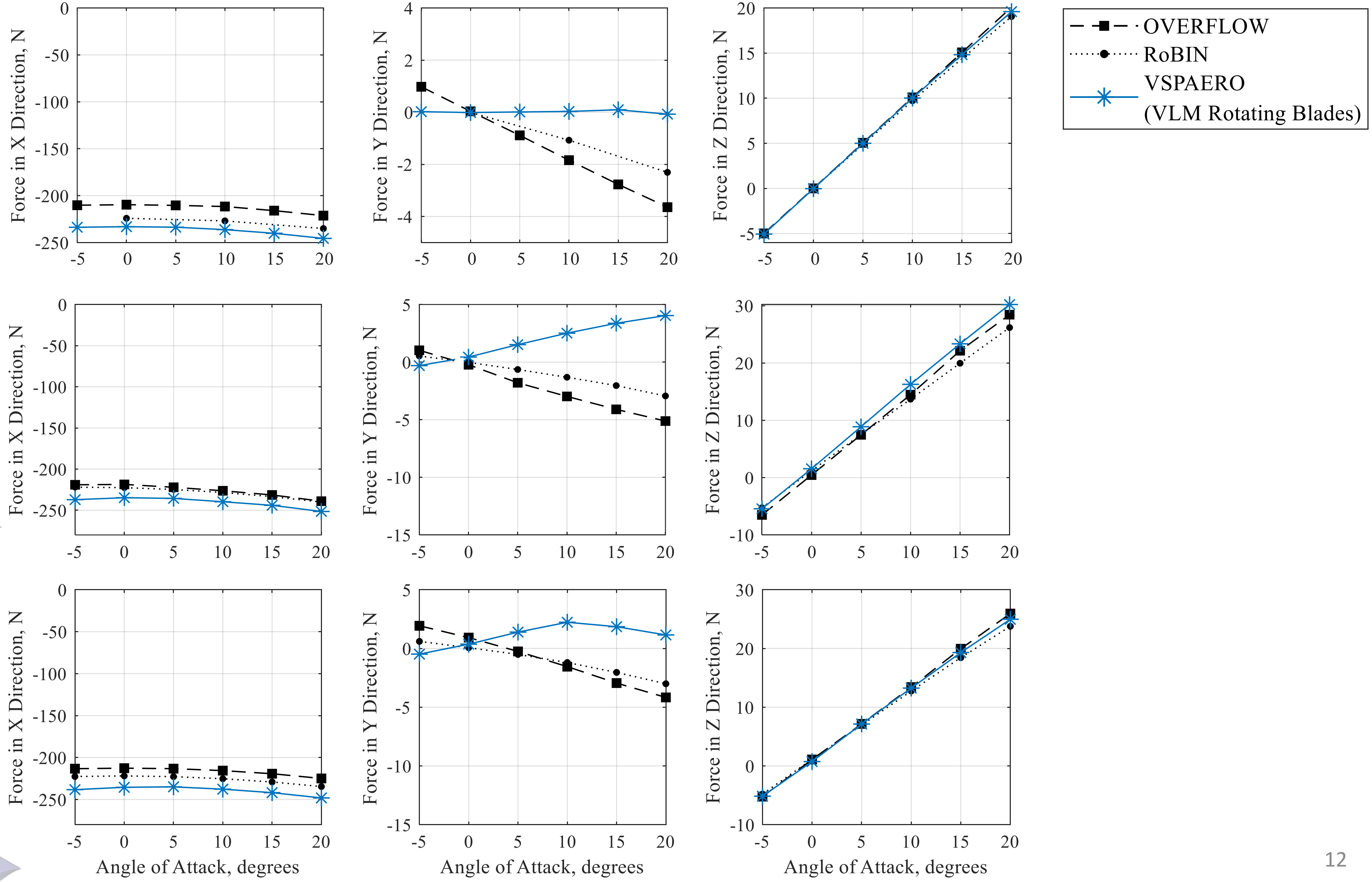


Midspan Configuration
(Propeller Component Only)



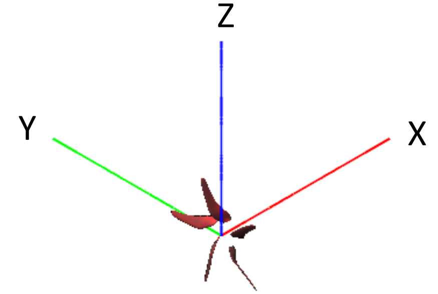
Wingtip Configuration
(Propeller Component Only)



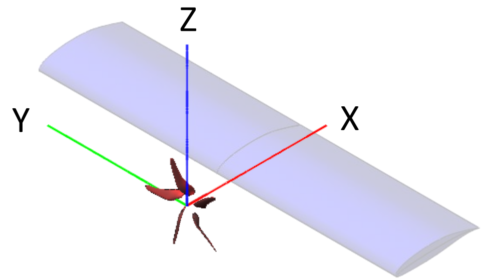


Propeller Component: Moments

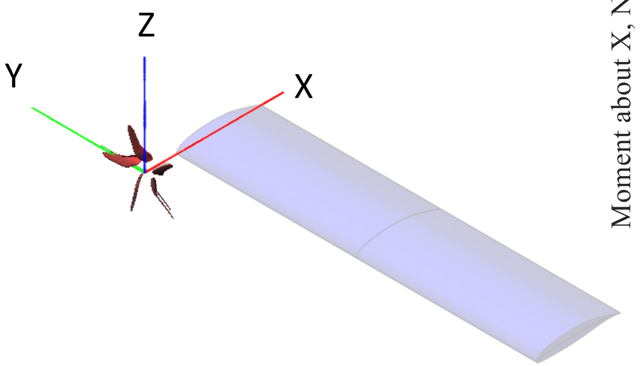
Propeller in Isolation

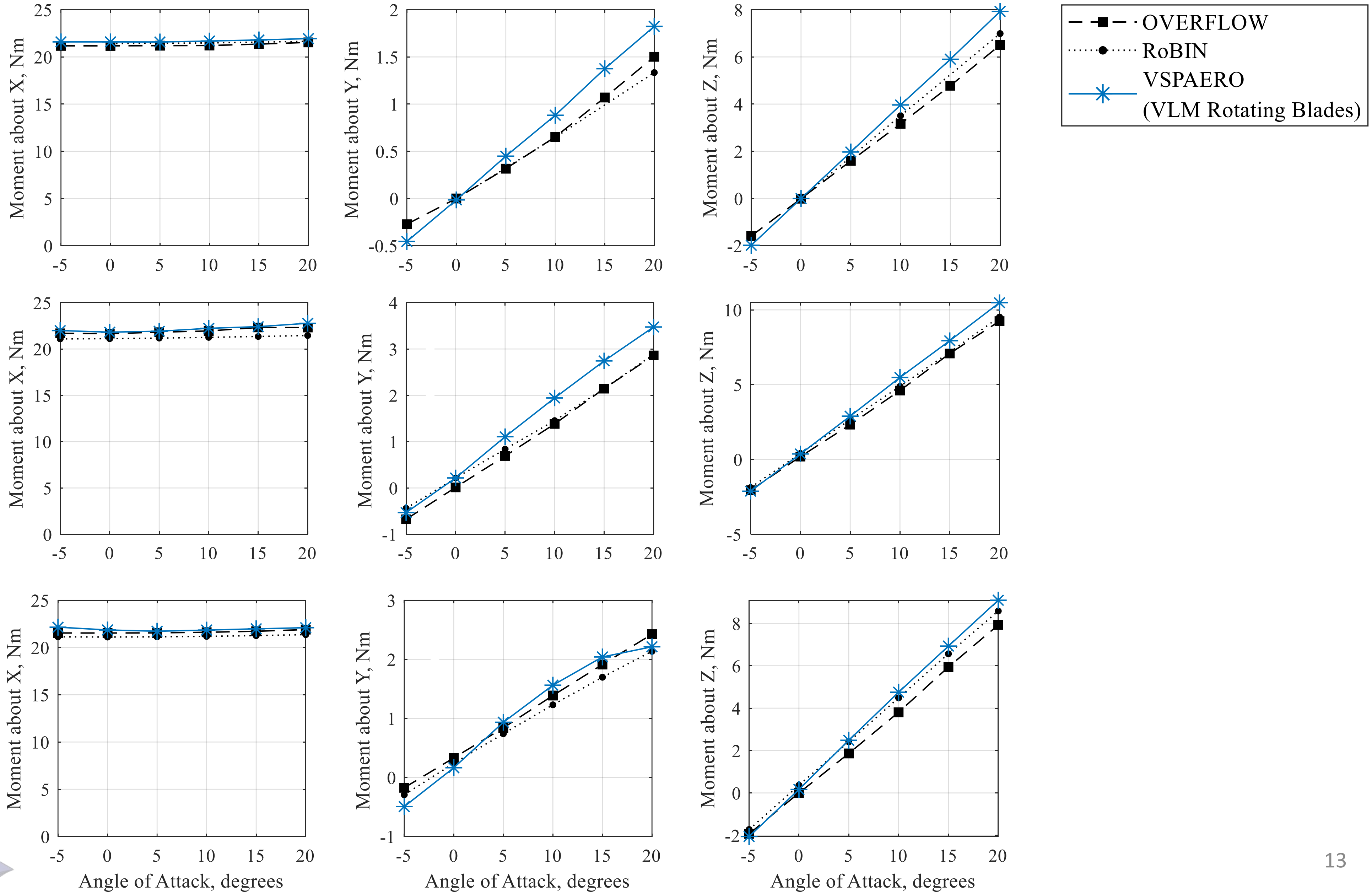


Midspan Configuration
(Propeller Component Only)



Wingtip Configuration
(Propeller Component Only)





Conclusions

- Agreement between VSPAERO and OVERFLOW force predictions indicates that VSPAERO may be valuable in the conceptual and early design phases where capturing the approximate solution quickly is of higher importance than obtaining a highly accurate solution
- VSPAERO moments predictions tend to be inconsistent relative to OVERFLOW, although predicted moments are generally within 15-20% of the expected range of values
- VSPAERO runs with an actuator disk required 98% less runtime than VSPAERO runs with rotating blades
- Further studies are recommended to investigate the wider applicability of VSPAERO in modeling other propeller-wing configurations and/or flight conditions.

Acknowledgments

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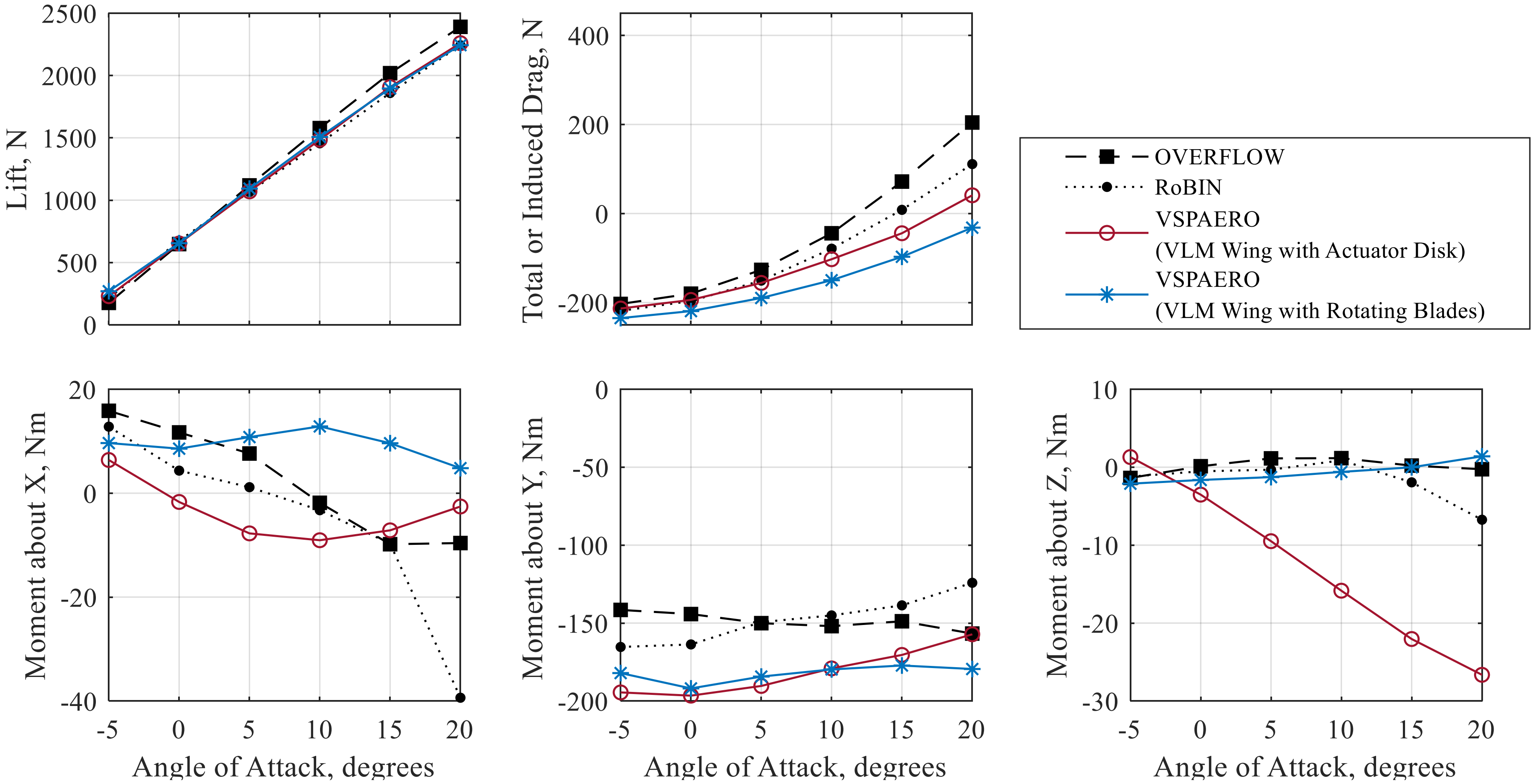
- Additional thanks to Brandon Litherland, Beau Pollard and Xiaofan Fei

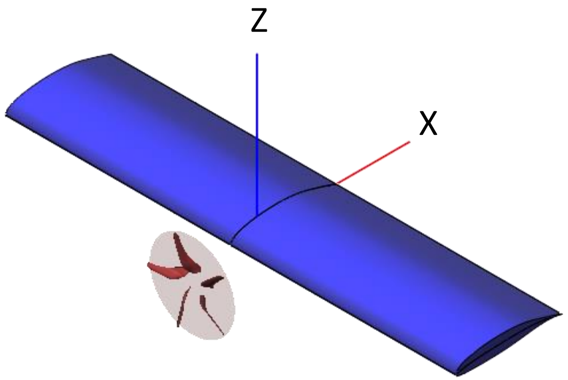
Thank you!

Questions & Answers?

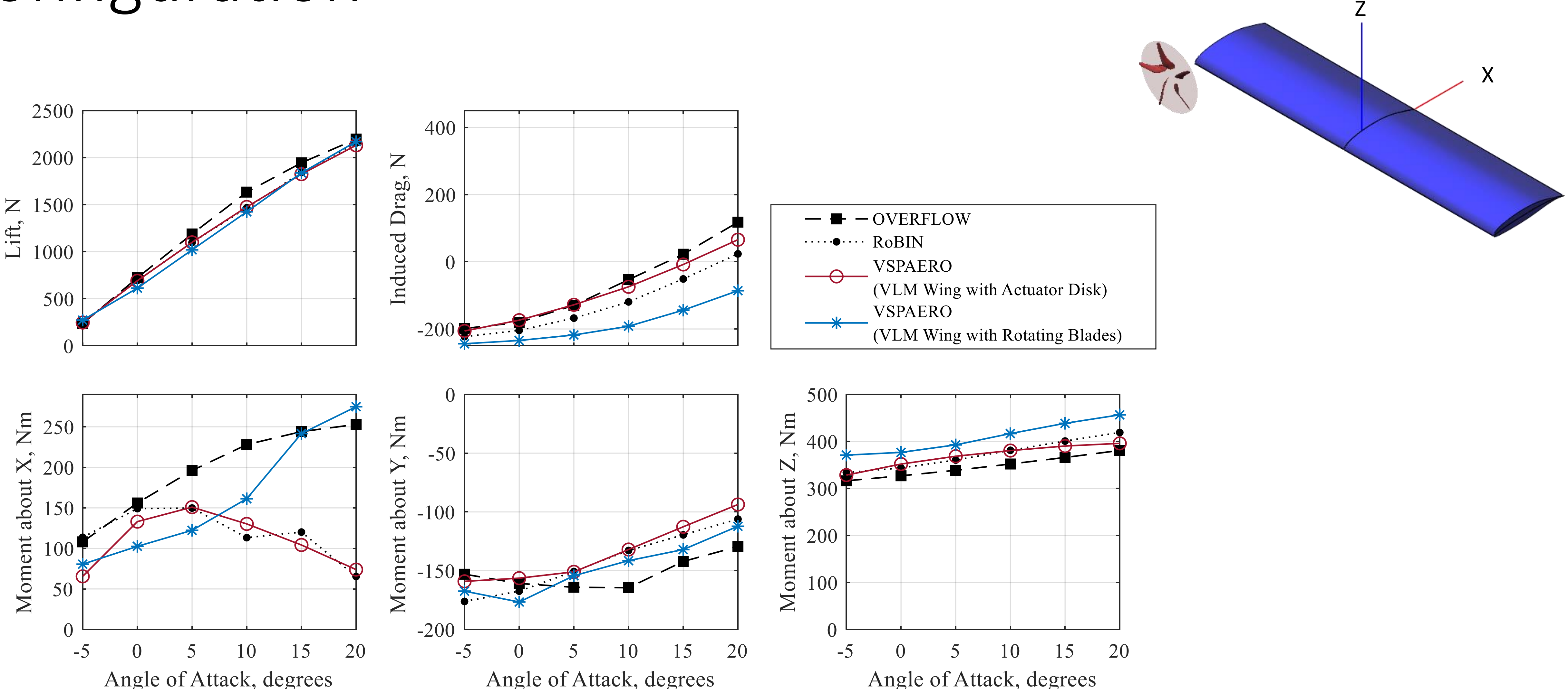
Backup

Total Forces and Moments: Midspan Propeller Configuration



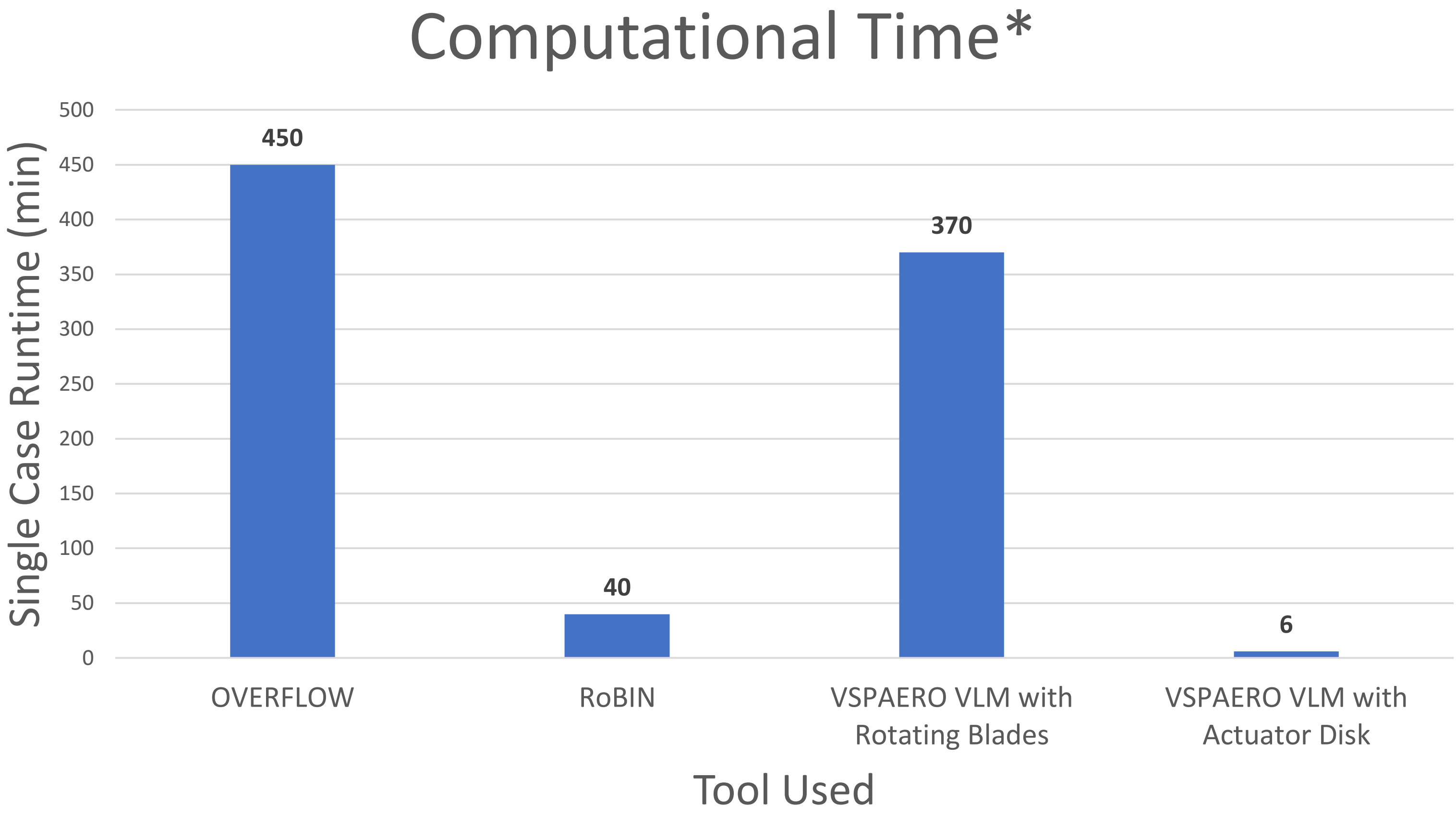


Total Forces and Moments: Wingtip Propeller Configuration



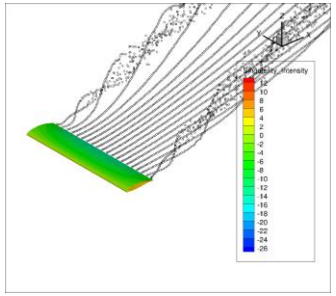
Computational Times

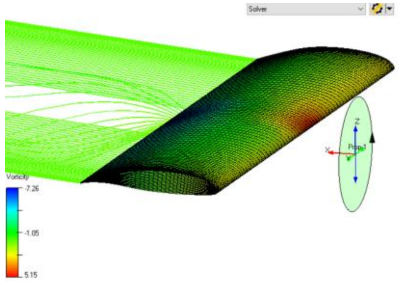
- OVERFLOW
  - Intel Xeon Processor E5-2670 CPUs (x16)
- RoBIN
  - Intel Xeon Platinum 8160 CPUs (x2)
  - Accelerated by NVIDIA Tesla P4 GPUs (x4)
- VSPAERO
  - Intel Xeon Gold 6148 CPUs (x4)
  - Rotating blades slower than RoBIN, but less computing power dedicated



Note: Since the RoBIN, OVERFLOW, and VSPAERO predictions were generated using different computing resources, only an informal account of computational times is provided

Recommended Future Work





- Further investigation is recommended for:
  - Impact of time steps on mesh convergence for unsteady propeller-wing analysis
  - Impact of number of iterations on mesh convergence
- Compare OVERFLOW predictions to predictions by other accessible tools, for example:
  - DUST: open source, vortex particle method developed by Polytechnic University of Milan
  - FlightStream: commercially available surface vorticity solver

- Additional VSPAERO validation studies for other configurations, for example:
  - NASA X-57 fully blown wing
  - NASA Tiltwing UAM reference vehicle